Identification, Remediation, and Monitoring Processes Used in a Mold-Contaminated High School

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I. Introduction

Microbiological, chemical, and particulate components of indoor air all can have a potential effect on occupant health. The levels of these components can be influenced by building design; heating, ventilation, air conditioning (HVAC) system design; installation, operation, and

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maintenance; occupant activities; management policy/housekeeping practices; and renovation and expansion projects. Poor indoor air quality (IAQ) is associated with a range of human health symptoms (Flannigan *et al.*, 1994; Redlich *et al.*, 1997) and with sick building syndrome (SBS). The World Health Organization first coined this term in 1982. SBS encompasses the effects of air toxics (airborne particulate matter and volatile organic compounds originating from new building materials, etc.) and in particular, the effects of airborne fungi and their products (Cooley *et al.*, 1998; Górny *et al.*, 2002; Mahmoudi and Gershwin, 2000).

The effects of fungi on human health can be broadly divided into three categories: (1) allergic reactions, including asthma-like symptoms (Cooley *et al.*, 2000; Fogelmark *et al.*, 1991; Licorish *et al.*, 1985); (2) fungal infections; and (3) responses to fungal products such as mycotoxins and volatile organic compounds (Bondy and Pestka, 2000; Pitt *et al.*, 2000; Yang and Johanning, 2002). Studies on the effects of inhaled mycotoxins have linked them to immunosuppression, liver damage, pulmonary dysfunction, and carcinogenesis (Hollinger and Ekperigin, 1999; Jakab *et al.*, 1994).

The presence of toxigenic molds in buildings has the potential to negatively affect human health (Redd, 2002), and work has shown that occupants of mold-affected buildings have significantly higher incidences of SBS-related disorders (Johanning, 1996). Further, the removal of toxigenic molds from affected buildings results in improved occupant health status (Jarvis and Morey, 2001; Sudakin, 1998).

The creation of acceptable IAQ in human-occupied dwellings can be a complex issue. This chapter presents a case study whereby a series of protocols was used to identify mold-related problems in a school building complex, remediate the school to the point where IAQ was considered acceptable, and then monitor the IAQ of the school after remediation.

II. Environmental Survey

Management staff from a 3-year-old high school in southern Texas had been dealing with comfort problems associated with excessive humidity and temperature fluctuations since the opening of the school. Concern regarding the IAQ of the building had also been expressed by staff and students to the administration. At one point, students and staff refused to enter the school buildings. An IAQ company was contacted to investigate the problem. An initial step by the company was to administer a survey to school staff. This survey was adapted and

developed from a previous National Institute of Occupational Safety and Health (NIOSH) epidemiological survey (Crandall and Sieber, 1996). Survey questions first addressed occupant health (e.g., type, frequency, and duration of symptoms; whether or not symptoms lessened after absence from building). Survey questions were then directed towards the workplace environment (e.g., private versus open work areas, number of people in area, physical observation of leaks in ceiling, walls and floors, remediation status of leaks plus the time delay in remediation after any leaks are observed, noted temperature swings, status of heating system and status of maintenance schedules, etc.). The analysis of the responses involved statistically comparing them to responses from a database of schools that did not have an IAQ problem.

A. Results and Conclusion

Of the 215 survey forms distributed, 187 were returned (87% response rate) and analyzed. The survey indicated that 28.4% of the occupants were experiencing symptoms related to the building and 9.6% of the occupants were experiencing symptoms potentially related to the building. The incidences of both mucosal and neurological symptom profiles were high compared with the means of other schools without poor indoor air quality (Figs. 1 and 2). Water event scores were

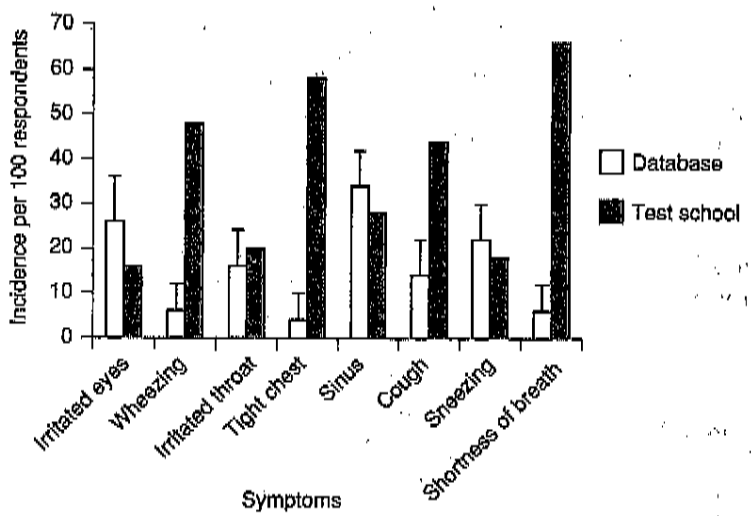

FIG. 1. Mucosal symptom scores from a test school suspected of having poor indoor air quality as compared with means and standard deviations of other schools with good indoor air quality.

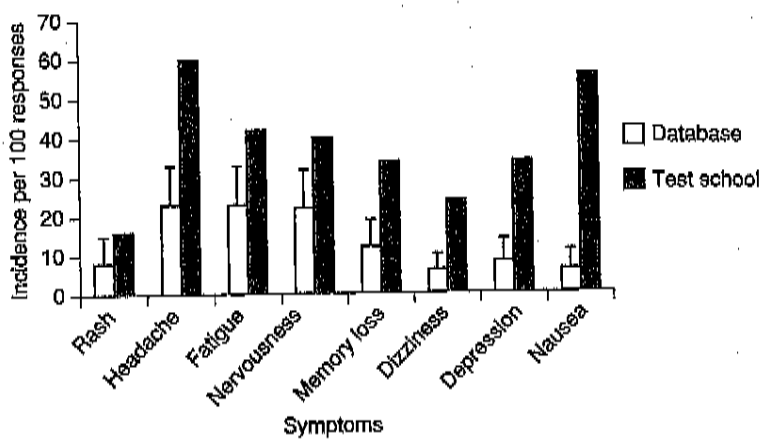

FIG. 2. Neurological symptom scores from a test school suspected of having poor indoor air quality (IAQ) as compared to means and standard deviations of other schools with good IAQ.

high as well, indicating nearly constant sources of moisture, which could lead to microbial growth. In addition, the responses to the survey indicated that strong musty odors were present, which is a common trait of interior mold growth. It was concluded that a full indoor air quality baseline investigation was required.

III. Initial Indoor Air Quality Investigation

The baseline investigation consisted of a number of steps. These were as follows:

A. Walk Through

An initial walk through was conducted. This is a process whereby technicians examined the structure internally and externally for evidence of mold growth and/or any obvious or subtle signs of water intrusion (Summerbell, 1995).

B. HVAC System

The HVAC system is the primary means for maintaining control of moisture in a dry building. It is also the primary transport mechanism for airborne pollutants (Hiipakka and Buffington, 2000; Simmons and Crow, 1995). Once the conditions are suitable for fungal growth to be

established in a building, the HVAC system can transport pollutants to other potential growth areas. The HVAC system was examined for design flaws, construction defects, and histories of operational failures.

C. Moisture Profiles

Relative moisture levels inside walls, etc., were ascertained with the use of a moisture meter (Tramex Moisture Encounter, Tramex, Ltd., Littleton, CO) throughout the building.

D. Air and Surface Samples

Airborne microbiological testing was performed in classrooms throughout the school. Culturable fungal samples were collected by using a two-stage Andersen biological cascade impactor (Thermo Andersen, Smyrna, Georgia). The samplers were run for 5 min with a calibrated vacuum pump (28.3 L/min) on to Sabourauds Dextrose Agar (SDA) plates (Burge *et al.*, 1977; Hoekstra *et al.*, 2000) (Fisher Scientific, Pittsburgh, Pennsylvania). An Allergenco air sampler (Mk 3. Allergenco/Blewstone Press, San Antonio, Texas) was also run in conjunction with the Andersen air sampler. This machine was run for 5 min. It collected non-culturable fungal spores, culturable fungal spores, and other particulates in the air. To evaluate the findings, results from the Andersen and Allergenco air samplers were compared with outside air samples taken with the same instruments.

Surfaces that on visual inspection appeared to have fungal growth were sampled with sterile swabs (Fisher Scientific, Pittsburgh, Pennsylvania) that were then placed in a sterile container, sealed, and labeled. A tape lift sample was also retrieved (St Germain and Summerbell, 1996).

E. Sample Identification

The agar plates from the Andersen sampler were incubated for 7 days at 24 °C before being read. Fungal cultures were identified with the use of reference texts after examination of colony morphology and microscopic examination of spores and hyphae (St Germain and Summerbell, 1996; Sutton *et al.*, 1998). Cultures employing Potato Dextrose Agar (PDA) and Malt Extract Agar (MEA) were also used where necessary to sub-culture and identify unknown fungi. The number of different fungal species was recorded as well as the numbers of individual colonies within each species. Results were expressed as the

total number of colony forming units (CFU) retrieved per cubic meter of air. Microscope slides from the Allergenco air sampler were read at 400× on an Olympus BH laboratory microscope (GMI Inc., Clearwater, Minnesota). Results included the identification and the enumeration of fungal spores, expressed as spores per cubic meter of air.

From surface samples, the tape lift was stained with lactophenol cotton blue (Fisher Scientific) and the microscope slides were then read at 400× on an Olympus BH laboratory microscope. Swabs were placed in 10 ml sterile tubes and had 5 ml of phosphate buffered saline (PBS) added to them. After a period of 5 h, the swabs were serially diluted in PBS, and 0.1 ml of these dilutions was then added to SDA, PDA, and MEA plates. The media were incubated for 7 days at 24°C. After this period, the plates were read by using the same procedures as for the Andersen sampler agar plates.

F. Other Measurements

Temperature and relative humidity measurements were taken to determine whether the dew point had been reached inside the building. Particulates in sizes ranging from 0.3 μm to 5.0 μm were also taken in conjunction with the airborne samplings to determine whether there was a high particulate count in the air. An airborne particle counter (APC-1000 Biotest Diagnostics, Denville, New Jersey) was used to count particles relative to four thresholds: >0.3, 0.5, 1.0, and 5.0 μm.

IV. Results of Initial Investigation

A. Walk Through

Sagging and stained ceiling tiles and a rusted ceiling grid system and light fixtures indicated an excessively wet environment. *Stachybotrys* sp. growth was discovered in several locations, primarily on the insulation of the chilled water piping system located in various mechanical rooms. Rust was also observed on structural members. Other general deficiencies observed were the presence of roof leaks and cracks in masonry walls caused by foundation movement. A physical examination of the fiberglass insulation above the ceiling tiles showed the presence of moisture, which may have been trapped by the insulation material. Loose floor tiles and adhesive seeps were also noted. It appeared that the overall building design and the placement of vapor retaining insulation allowed condensation to take place in interstitial spaces.

B. HVAC System

The conclusion was that the design of the outside air system in providing ventilation, coupled with the building air conditioning system design, was insufficient to properly condition and/or treat the outside air. This created conditions in the building that led to discomfort, condensation, and fungal proliferation. Specific issues were: the dew point of the outside air for ventilation was not sufficiently depressed. The chilled water system piping was undersized. The air handling unit (AHU) control valves were leaking and not seating properly. The set point of the chilled water was too low in an attempt to overcome undersized piping and marginal primary/secondary loop design/installation, resulting in improper operation. The fiberglass insulation material on piping was not appropriate for hot and humid environmental conditions. There was poor workmanship in the installation of the insulation system and sealing of the vapor barrier. The condensate drain systems did not have a sufficient slope or were leaking, resulting in air conditioning pan overflows. The control systems sequences of operation of the outside air system were allowing non-conditioned air to enter the building during the "off" period.

C. Air and Surface Samples

Table I shows some representative findings from the air sampling. The 31 samples taken did not suggest a contaminated environment; total CFU counts inside were lower than outside. *Cladosporium* sp. were the dominant fungi in the outside air. With the exception of one room, *Cladosporium* sp. were dominant in all inside samples. Results of the spore traps revealed that inside counts were a reflection of outside counts.

Culturable fungal growth sites were found on a number of substrates. These included *Stachybotrys* sp. and *Aspergillus* sp. Growth sites were found on chilled water piping, on ceiling insulation, and on a variety of other surfaces.

V. Indoor Air Quality Investigation: Conclusion

Although there was not an indication of a mold problem from the air samples, the findings from the walk through and the results of the HVAC profiles led to the conclusion that the inability of the HVAC system to effectively dehumidify indoor air meant that all surfaces and materials were at risk of condensation and fungal growth. A decision

TABLE I

PRE-REMEDIATION MICROBIOLOGICAL AIR SAMPLE RESULTS FROM LOCATIONS IN A HIGH SCHOOL SAMPLED WITH AN ANDERSEN AIR SAMPLER

	Fungal genera				
Location	*Cladosporium*	*Penicillium*	*Aspergillus*	*Alternaria*	*Bipolaris*
OAS 1	182		21		28
OAS 2	91	28			7
OAS 3	238			42	
OAS 4	287			42	
Library	91				21
Gym	28	14			28
Cafeteria	182	21			14
Band	28				7
L204	161	21			
L203	126	49			
L201	182				14
L105	84				
L101	28				21
D204	56	14			
D202	14	14			
D111	35			7	7

OAS = outside air sample. Results expressed in Colony Forming Units/m^3 air.

was made to address the cause of the excessive moisture and to commence with the remediation process.

VI. Abatement, Decontamination, and Clearance

A. General Considerations

All work was directed to creating an environment free of mold growth sites and one where air temperatures were between 72° and 76 °F and relative humidity between 45% and 55%. Importantly, fresh air was to be conditioned to 45 °F dew point and approximately 70 °F before being distributed to the occupied space (American Society for Heating Refrigeration and Air-Conditioning Engineers, 1989). All work was conducted after students and staff vacated the building.

B. Drying the Building

Removal of excess absorbed moisture in building materials inside the building and the lack of conditioned or dehumidified outdoor air for ventilation was temporarily addressed with the use of eight portable desiccant dryers (Munters Titanium Silica Gel Desiccant wheel, Texas Manufacturing Center, Selma, Texas) connected to the existing outside air intakes. The desiccant driers lowered the vapor pressure in the building, thereby facilitating drying of structural components (poured roof deck, fireproofing, masonry construction, etc.) and contents.

C. Containment

Prior to remediation, areas were selected and put into containment as per the Environmental Protection Agency (2001) and the New York City Department of Health guidelines (1993). Inside the contained areas, high-efficiency particulate air (HEPA) filter negative air systems were installed whereby air was drawn from the outside of the containment area into the containment area, circulated, then exhausted directly to the outside air. This system allowed for any fungal spores liberated during remediation to be collected in the HEPA filters. Once this was completed, remediation began. Personnel working inside containment were required to wear TYVEK™ protection suits (Texas America Safety Company, South Brownwood, Texas), rubber gloves, and full-face respirators fitted with P100 filters (National Institute of Occupational Safety and Health, 1995).

D. Removal of Contaminated Items

The removal of mold-contaminated materials can have a direct positive effect on IAQ (Ellringer *et al.*, 2000), therefore all visible mold growth sites were removed. This included the removal of all contaminated building materials, ceiling tiles, fiberglass insulation above both drywall and lay-in ceilings, and chilled water insulation. Carpet was replaced with vinyl composition tile in most areas. Areas around the contaminated items were also cleaned with a 70% alcohol solution (Steri-Fab, Yonkers, New York). The ceiling tiles were replaced with a moisture-resistant tile (1729A HumiGuard, Armstrong World Industries Inc., Minneapolis, Minnesota).

E. HVAC Reconditioning

All air handler units (AHU) and ductwork were cleaned in accordance with industry specifications (National Air Duct Cleaning Association, 1992). This included fan coils and air handler units. The condensate drain system for the fan coil units was redesigned and replaced, drain receivers were relocated, and trap primers were installed. All interior surfaces of the AHU casing and the first 12′ of supply air duct were coated with an anti-microbial agent (Aegis Environmental [Atlantic] Ltd., Nova Scotia, Canada). However, note that this anti-microbial treatment is still under evaluation by the Environmental Protection Agency. The coils were coated with an anti-foulant (First Strike Micro Coat, Controlled Release Technologies, Inc., North Clearwater, Florida). The fiberglass jacket for the chilled water insulation system in the building was replaced with a phenolic foam (Extol of Ohio, Norwalk, Ohio) with an all-service jacket (ASJ). The condensation drain lines were insulated with Armaflex (Armstrong World Industries, Lancaster, Pennsylvania). A portion of the supply air was redirected to the space above the ceiling to keep the building elements in that space environmentally stable. An engineered outside air ventilation system that incorporated desiccant dryer technologies (Munters Titanium Silica Gel Desiccant Wheel, Texas Manufacturing Center, Selma, Texas) was permanently installed to replace the portable desiccant dryers. This conditioned the outside air for ventilation to a 45 °F dew point and approximately a 70 °F dry bulb temperature before being distributed to air handling units and fan coil units serving the occupied spaces.

VII. Clearance Testing: Methods and Results

After each area had been remediated, a preliminary clearance test was performed, which involved the use of spore traps, tape lifts, and most importantly, a practical assessment of the remediation efforts in conjunction with a visual inspection of the remediated area. Spore trap levels of indoor airborne fungi needed to be equal to or lower than the outdoor levels, with a similar rank order and composition (or less than) of mold types present in outside air. If a spore trap result was considered unacceptable, the area was re-examined for fungal growth; the area in the area was also "scrubbed" with a negative air machine for a total of 24 h. The area was then re-sampled. If an area was judged acceptable it would then be taken out of containment. This judgment was a subjective one based on the air sample results and an evaluation of

the remediation work. At this point workers were no longer required to use respirators and wear protective clothing such as chemical protection suits and rubber gloves. Final cleaning and general maintenance was then conducted, at the completion of which a final clearance test was performed. This involved the use of culturable and non-culturable fungal sampling and an overall consideration as to the success of the remediation effort.

VIII. Post Remediation

After completion of the remediation and cleanup process, the school was handed back to the school administrators. An ongoing monitoring system was then initiated. The school was examined sequentially at 30-day intervals during which time air samples were collected and physical inspections conducted.

IX. Discussion

The school was typical of many schools in this geographic region in that the buildings are well sealed to conserve energy costs. This type of construction has been associated with poor IAQ (Addington, 2001). In a well-sealed building, a defective HVAC system has the potential to cause widespread problems. This situation can be exacerbated by local water intrusions resulting from roof leaks, etc. Remediation can be an expensive and time-consuming process, therefore it is advisable that strict attention is paid to the HVAC operations and to any evidence of moisture intrusion. It is axiomatic that the control of moisture leads to the control of mold. The high numbers of defects in the HVAC system were the principal reason for the moisture levels that allowed mold to grow in this school.

The remediation process did not include the cleaning of contents inside the school by the remediation company. This was conducted by the custodial and maintenance staff of the school with conventional cleaning techniques. General guidelines for contents cleaning have been proposed (EPA, 2001), and work has been conducted in this laboratory regarding appropriate cleaning methodology (Wilson *et al.*, in press). A significant issue in the mold identification process was the disparity between results of the microbiological air samples and the observations of mold growth sites and the results of the mold survey. This is because air samples are often not representative (Burge, 2001). Some of the reasons for this are that the process of sporulation is not constant with certain fungal species. Sporulation is triggered by a

number of factors such as temperature and humidity (Yang and Johanning, 2002), and air sampling may take place during intervals between sporulation. Also, some fungi such as *Stachybotrys chartarum* produce a relatively wet and heavy spore compared with other fungi such as *Penicillium* sp., which may partially account for the low rate of capture of this organism in air samplers. The culturability of fungal conidia also plays a role, although this issue is addressed if a spore trap is used in conjunction with a culturable air sampler. A separate issue is that there are no universally accepted levels for interpreting air samples. Currently the best approach is to compare the inside samples to the outside samples. Inside air should reflect the outside air in terms of types, levels, and rank orders of fungal organisms. Indoor air samples should not be interpreted in isolation. They need to be considered as a tool but not an autonomous criterion for passing or failing the air quality in buildings. Air sampling was employed as part of the clearance process in this school. However, the data were interpreted in the light of the limitations described above. Because of the limitations of the air sampling process, locating hidden mold in affected buildings still remains a challenge for indoor air investigators. While the occupant survey is one tool, others include visual inspections and/or the taking of air samples of building cavities (WallChek, SKC, Eighty Four, Pennsylvania). In the future, techniques that identify microbial VOC (Gao and Martin, 2002) and the analysis of fungal DNA in air samples may lead to improved detection rates of hidden mold (Cruz-Perez *et al.*, 2001; Roe *et al.*, 2001).

X. Conclusion

In this case study, a mold-related epidemiological survey in conjunction with indoor air quality technician observations was effective in identifying mold problems in a contaminated high school. Techniques such as dehumidification of the outside air for the HVAC system, the reconditioning of the HVAC system, and the physical removal of mold growth sites were used in the remediation process. Post remediation monitoring processes indicate that these techniques have been successful.

XI. Recommendations

HVAC systems need to be carefully evaluated with regard to their potential for creating excessive moisture in well-sealed schools. Air samples are prone to false negatives and should be interpreted cautiously when assessing mold contamination of school buildings.

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